

# Allometric Models for Aboveground Biomass of Benguet Pine (*Pinus kesiya*)

Jones T. Napaldet, Dr. Romeo A. Gomez Jr.

**Abstract** – Several authors recommend species-specific allometric models for accurate carbon sequestration accounting but mixed-species models are prevalent in the Philippines. Thus, in the study, species-specific models were developed for above-ground biomass of Benguet pine (*Pinus kesiya*). Diameter at breast height (D) and total tree height (H) were primarily used as the dependent variables. Wood density, with values ranging from 0.34 to 0.59 g/cm<sup>3</sup>, was also explored as a dependent variable but it yielded low correlation and models with low r<sup>2</sup> values. This supports other studies claiming that wood density is more apt in mixed-species than in species-specific models. Best-fit models for total above ground biomass (TAGB = 0.067D<sup>2.474</sup> and TAGB = 0.0000003855 (D<sup>2</sup>H)<sup>2</sup> + 0.023 (D<sup>2</sup>H) + 3.496) and for the other tree compartments for a total of 16 models were developed. These models have high r<sup>2</sup> and adjusted r<sup>2</sup> values of 0.87 to 0.99. Moreover, these models yielded more accurate estimates of Benguet pine biomass than mixed-species models of Brown & Schroeder (1999) and Chave et al. (2005). Thus, the study highly recommends these models for accounting Benguet pine biomass and subsequently, the carbon it sequestered.

**Index Terms** – Allometric models, Benguet pine, wood density

## 1. INTRODUCTION

Carbon sequestration, the practice of capturing CO<sub>2</sub> in a reservoir to keep the gas from being released to the atmosphere, has been identified as one way to offset or mitigate global warming and climate change (OECD, 2001). Its implication to the Philippines could be better appreciated in the context of emission trading and carbon credits. This involves giving monetary value to pollutants in the atmosphere and the reduction thereof. Countries that were parties to the treaty could sell carbon credits for US\$ 15 to 25 per ton of sequestered carbon (Fletcher & Parker, 2003; Bengwayan, 2010).

Biomass is an important indicator of carbon sequestration levels since 50% of the forest biomass is supposedly carbon (Montagnini & Porras, 1998; Losi et al., 2003; Montagu et al., 2005). The Kyoto Protocol requires transparent reporting of forest removal and accumulation (biomass change). This implies the use of precise procedure to quantify forest biomass and its uncertainty.

Majority of the studies conducted on Philippine forest primarily use generic mixed-species allometric models to estimate biomass. This method is non-destructive and easier to conduct; however, the accuracy of the model is often questionable and limited (Ketterings et al., 2001; Segura & Kanninen, 2005; Tinker et al., 2008; Ebuy et al., 2011). Thus, to attain an accurate accounting of the carbon stock, there is a need to develop models based on biomass data from the local forest. Hence, this study was conceptualized.

*Pinus kesiya* dominates the montane rainforests or pine forests of the Cordillera Administrative Region in Northern Philippines. Being the dominant species, *Pinus kesiya* could be inferred to contain the major bulk of carbon in the forest. The study determined the best-fit models for the aboveground biomass of Benguet pine and its compartment (trunk, primary branch, secondary branch, twigs and needles) based on destructively sampled trees.

## 2. MATERIALS AND METHODS

The study sampled 15 pine trees in the communal secondary pine forest of Batayan, Tadian, Mountain Province – 5 trees for each diameter class ranges (5-10, 11-30, and 31-50 cm) were felled. Each tree was compartmentalized into main trunk, primary branch, secondary branch, twigs and needles. These were summarized to get the total above-ground biomass. Samples from these different tree compartments were oven-dried to determine the moisture content and then deducted from the freshweight to derive the dryweight or biomass. Wood density was also determined using water displacement method (Basuki et al., 2009).

Biomass data were subjected to correlation and regression analysis using SPSS to develop allometric models. Correlation analyses were first employed to establish the relationship between the easily measured (independent) variables such as D, H and wood density with the trees' aboveground biomass (dependent). Also, a graphical exploration of the data was conducted to avoid falling into the traps of 'blind' fitting; the impression can be gained that the model accurately fits the data, whereas in fact this result is an artefact (Picard et al., 2012). The coefficient of determination (adjusted r<sup>2</sup>) for each model was used to assess the accuracy of the model. The higher the adjusted r<sup>2</sup> value, the higher the accuracy of the model (Kahane, 2001), thus allometric models with the highest

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adjusted  $r^2$  value were selected and proposed for biomass estimation. Models developed in the study were compared with the generic allometric models developed by Brown and Schroeder (1999) for pine forest as cited in Pearson et al. (2007) and Chave et al. (2005) for wet forest stand using paired t-test (Tinker et al., 2008).

### 3. RESULTS

#### 3.1. Developing allometric models for biomass estimation of Benguet pine

Pearson Correlation showed very high correlation ( $p=0.00$ ) between D and H with the aboveground biomass and its compartments. This, and the scatter plots (Fig. 1 and 2) established D and H as independent variables in the study.

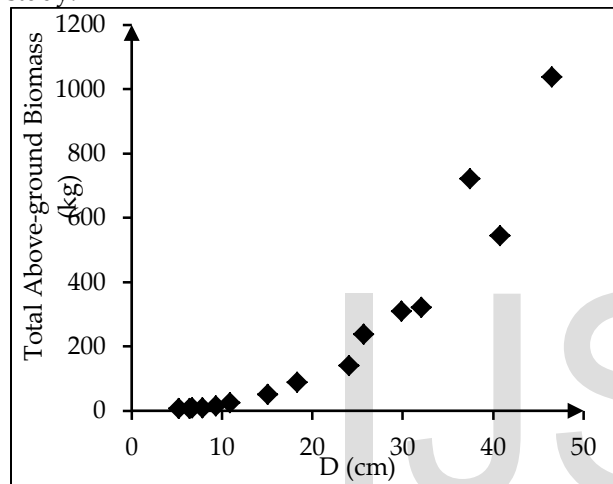


Fig. 1. Scatter-plot showing the relation between the D with total aboveground biomass

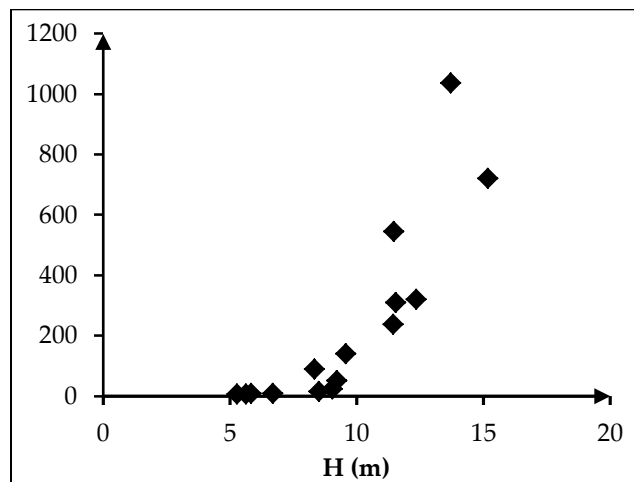


Fig. 2. Scatter-plot showing the relation between the H with total aboveground biomass

Table 1 presents the allometric models best-fitted for the aboveground biomass and its different compartments. Two equations per biomass component were selected: <sup>1</sup>models with D as the only independent variable; and, <sup>2</sup> models with the combined effect of D with H ( $D^2H$ ).

Best-fitted allometric model for total aboveground biomass were  $TAGB = 0.067D^{2.474}$  and  $TAGB = 0.0000003855 (D^2H)^2 + 0.023 (D^2H) + 3.496$ . These models have high  $r^2$  and adjusted  $r^2$  values ranging from 0.87 to 0.99 indicating very good fit, with the 2<sup>nd</sup> models having slightly higher values. Also, these equations have low p-values and high F-values thus, complying with requirement for goodness of fit for allometric models.

Table 1. Allometric models for the estimation of Benguet pine biomass

Tree Biomass (kg)	Allometric Models	$r^2$	Adjusted $r^2$
Total	$=0.067 D^{2.474}$ or	0.991	0.990
Above-Ground Biomass	$=0.0000003855 (D^2H)^2 + 0.023 (D^2H) + 3.496$	0.994	0.993
Main Trunk Biomass	$=0.068 D^{2.321}$ or	0.989	0.989
	$=0.0000001531(D^2H)^2 + 0.016 (D^2H) + 0.976$	0.994	0.993
Primary Branch Biomass	$=0.189 D^2 - 4.770 D + 27.35$ or	0.965	0.959
	$=0.0000001749 (D^2H)^2 + 0.002 (D^2H) + 1.593$	0.971	0.967
Secondary Branch Biomass	$=0.015 D^{2.264 na}$ or	0.887	0.871
	$=0.006 (D^2H)^{0.938 na}$	0.917	0.905
Total Branch Biomass	$=0.001 D^{3.232}$ or	0.960	0.957
	$=0.0000001633(D^2H)^2 + 0.006(D^2H) + 0.594$	0.990	0.989
Twigs Biomass	$=0.005 D^{2.237}$ or	0.946	0.941
	$=0.00000002597(D^2H)^2 + 0.000 (D^2H) + 1.003$	0.972	0.967
Needles Biomass	$=0.008 D^{2.356}$ or	0.958	0.955
	$=0.003(D^2H)^{0.976}$	0.963	0.960

D = diameter at breast height (cm)

H = Total tree height (m)

na = not applicable for 5 -10 cm dbh trees since they have no secondary branch

#### 3.2. Comparison with Other Models

Brown and Schroeder model for general pine forest stand ( $TAGB = 0.887 + (10486 \times D^{2.84})/D^{2.84} + 376907$ ) yielded significantly different estimates (paired t-test,  $p=0.026$ ) compared with the actual biomass. It underestimated the biomass of smaller trees while overestimated for larger trees with better agreement at intermediate D trees. Chave

et al. model for wet forest stand ( $TAGB = 0.0776 \times (p \cdot D^2 \cdot H)^{0.940}$ ) provided consistently lower estimates, though, not statistically significant ( $p=0.086$ ).

The two models developed in study ( $TAGB = 0.067D^{2.474}$  and  $TAGB = 0.0000003855 (D^2H)^2 + 0.023 (D^2H) + 3.496$ ) generated estimates that were not significantly different from the actual biomass ( $p=0.481$  and  $0.643$ , respectively). The 2<sup>nd</sup> model gave estimates that follow the rise and fall trend of the actual biomass. Refer to Fig. 3 for comparison between the estimates of the models with the actual biomass.

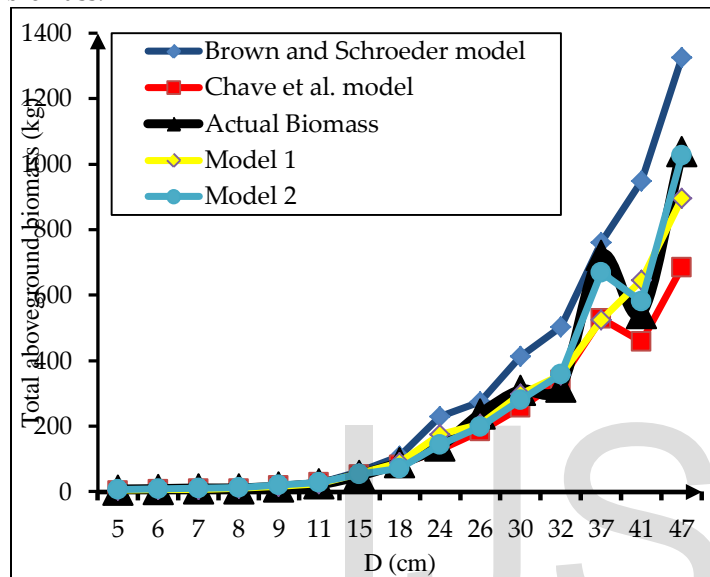


Fig. 3. Comparison of the predicted biomass with the actual biomass (Model 1  $TAGB = 0.067D^{2.474}$ ; Model 2  $TAGB = 0.0000003855 (D^2H)^2 + 0.023 (D^2H) + 3.496$ )

### 3.3. Moisture content and wood density

The moisture content of the different tree compartments (Table 2) was more or less 50%. Woody compartments (trunks and branches) generally contained less water than herbaceous (twigs and needles) ones –54 & 61% <62&65% in 5-10 cm D trees; 52& 49 to 52% < 58 & 57% in 11-30 cm D trees; and, 49& 43 to 54% < 58& 56% in 31-50 cm D trees. Between diameter classes, larger diameter trees (52%) contained significantly lower mean moisture content than 5-10 cm D trees (60%).

Table 2. Moisture Content (%) of the different tree components

Tree components	Moisture Content (%) of the Tree Diameter Classes		
	5 – 10 cm	11 – 30 cm	31 – 50 cm
Main Trunk			
Base	54.0184 <sup>a</sup> I	47.4470 <sup>a</sup> I	52.9184 <sup>a</sup> III
Middle	53.0204 <sup>b</sup> I	50.2669 <sup>a,b</sup> I	46.1690 <sup>a</sup> I,II
End	55.0194 <sup>a,b</sup> I	57.5457 <sup>b</sup> II	48.6650 <sup>a</sup> II

Mean	54.0194 <sup>a</sup>	51.7532 <sup>a</sup>	49.2508 <sup>a</sup>
Primary Branch	60.5556 <sup>b</sup> I,II	49.1945 <sup>a,b</sup> I	43.2659 <sup>a</sup> I
Secondary Branch	n/a	51.9842 <sup>I,II</sup>	53.9715 <sup>III,IV</sup>
Twigs	61.9500 <sup>a</sup> I,II	57.9278 <sup>a</sup> II	58.3925 <sup>a</sup> V
Needles	64.7619 <sup>b</sup> II	56.9685 <sup>a</sup> II	56.6874 <sup>a</sup> IV, V
Grand Mean	59.8780 <sup>b</sup>	55.4405 <sup>a,b</sup>	52.4652 <sup>a</sup>

Means with the same letter in a row are not statistically different at  $\alpha=0.05$  DMRT

Means with the same numeral in a column are not statistically different at  $\alpha =0.05$  DMRT

Table 3 presents the wood density of the main trunk and branches of the sampled trees. Wood density of the main trunk ranged from 0.34 to 0.59 g/cm<sup>3</sup> with significantly lower values on 5-10 cm D class (0.46) compared to 11-30 cm D class (0.52) and 31-50 cm D class (0.55). Between trunk sections, generally the base was significantly denser than the middle and apical portion among the diameter classes (0.55>0.48>0.34 in 5-10 cm D class; 0.59>0.54>0.45 in 11-30 cm D class; and, 0.59>0.54>0.52 in 31-50 cm D class). Branch wood density, on the other hand, was significantly higher on large trees ranging from 0.57–0.69 compared to 0.44 of small trees. Interestingly, wood branch (0.60-0.63) of large diameter trees was denser than the main trunk (0.51-0.55).

Table 3. Wood density of the main trunk and branch

Tree Components	Wood density (g/cm <sup>3</sup> ) of the tree diameter classes		
	5-10 cm	11-30 cm	31-50 cm
Main Trunk			
Base	0.5581 <sup>a</sup> III	0.5870 <sup>a</sup> II,II	0.5897 <sup>a</sup> I,II
Middle	0.4793 <sup>a</sup> II,III	0.5402 <sup>a</sup> II	0.5367 <sup>a</sup> I
Apex	0.3448 <sup>a</sup> I	0.4172 <sup>b</sup> I	0.5238 <sup>c</sup> I
Mean	0.4607 <sup>a</sup>	0.5148 <sup>b</sup>	0.5501 <sup>b</sup>
Primary Branch	0.4370 <sup>a</sup> II	0.5685 <sup>b</sup> II	0.6875 <sup>c</sup> III
Secondary Branch	n/a	0.6812 <sup>III</sup>	0.5651 <sup>I</sup>
Mean	0.4370 <sup>a</sup>	0.6044 <sup>b</sup>	0.6336 <sup>b</sup>

Means with the same letter in a row are not statistically different at  $\alpha= 0.05$  DMRT

Means with the same numeral in a column are not statistically different at  $\alpha =0.05$  DMRT

## 4. DISCUSSION

### 4.1. Developing allometric models for biomass estimation of Benguet pine

For models with D as the only independent variable, power regression models (with a form:  $Y = aX^b$ ) estimated and fitted best all the biomass components except for primary branch. The  $r^2$  values (0.87 to 0.99) of these models were not much lower than the more complex models. Thus, it could be surmised that the D of Benguet pine is enough to estimate its total above-ground biomass with 87 to 99% accuracy – which is very advantageous since D is easier and more accurately measured in the field than tree height and other variables. According to Montagu et al. (2005) as cited in Litton and Kauffman (2008), the measurement error in getting the D of trees is only 3% while 10-15% for tree height.

Total tree height as sole independent variable was extensively explored but yielded equations with lower  $r^2$  values. This result is consistent with the study of Tinker et al. (2008) on lodgepole pine (*Pinus contorta* var. *latifolia*) which found out that D was the primary morphological predictor of all the trees' biomass compartment and H only as secondary. Also, this could be attributed to the higher correlation between D and biomass than between H and biomass.

For secondary branch, the combined effect of D and H as the independent variables resulted to higher  $r^2$  values than with D alone. However, D was squared first before multiplied with H ( $D^2H$ ) signifying D as the primary predictor and H only as secondary. This is consistent with Tinker et al. (2008) that identify tree height only as a secondary predictor for branch biomass. Nonetheless, equation using D was also generated for this biomass component since it is easily measured, albeit, with lesser  $r^2$  values ( $\approx$  lesser accuracy).

The same result was also observed in the allometric models for the other tree compartments such as twigs and needles. The combined effect of D and H yielded higher  $r^2$  values (0.96-0.97) but not much higher than D alone (0.94-0.95). Nonetheless, these  $r^2$  values were very high indicating fitness and accuracy of the models in predicting the biomass of these compartments.

Wood density was also explored as an independent variable. Several studies suggested the significance and inclusion of wood density in generating more accurate regression equations (Baker et al., 2004; Chave et al., 2005; Basuki et al., 2009; and Ebuy et al., 2011). However, this is not the case in the study. Wood density (both the main trunk and branch) yielded poor correlation with the biomass and models including wood density have low  $r^2$  values. Thus, it is not included in the best-fit regression equations. Nonetheless, related studies showed that wood density is more aptly used in mixed species models but not in species-specific models (Tinker et al., 2008 on lodgepole pine; and, Litton and Kaughman, 2008 on *Metrosideros* sp.).

## 4.2. Comparison with Other Models

Brown and Schroeder model yielded significantly different estimates from the actual biomass thus, it is deemed not accurate to predict the TAGB of *Pinus kesiya*. This is consistent with the findings of Litton and Kauffman (2008) where in general models like that of Brown and Schroeder's tend to greatly underestimate biomass at smaller D and greatly overestimate biomass at larger D, with better agreement at intermediate D trees. Chave et al.'s model, on the other hand, included wood density in their equation and yielded estimates not significantly different. It is observed that the deviation of the estimated values of these two models from the actual biomass is much greater on large diameter trees – overestimate for Brown and Schroeder's while under estimate for Chave et al.'s.

## 4.3. Moisture content and wood density

Larger D trees have lower moisture content since they are older and have accumulate more fiber cells over time than smaller D younger trees. Fiber cells are dead cells at maturity, have thicker cell walls and lesser watery cytoplasm while younger trees have more herbaceous parts. Between tree compartments, dead tracheids, vessel elements and fiber cells predominate in woody parts hence yielding lesser moisture content than the herbaceous parts (needles) which consist primarily of living parenchyma cells that are water saturated (Mauseth, 1998; Stern, 2000; and Microsoft Encarta, 2009).

Wood density of Benguet pine derived in the study fall under the normal range for *Pinus kesiya*: 0.43 to 0.50 g/cm<sup>3</sup> according to USDA Forest Service; 0.40 to 0.75 according to Prota; and 0.56 to 0.59 according to World Agroforestry Centre (n.d.).

## 5. CONCLUSIONS AND RECOMMENDATIONS

The study generated 16 allometric models for aboveground biomass of *Pinus kesiya* and its compartments using D and H as independent variables. These models had high  $r^2$  and adjusted  $r^2$  values of 0.87 to 0.99, thus, concluded to be accurate for estimation of the above ground biomass and hence could served as a guide in quantifying carbon in the forest, which, in turn, guides its monetization under the carbon sink and emission trading. With these  $r^2$  values, the study was confident that the predicted values of these models was less than 20% error set in the emission trading scheme under the Clean Development Mechanism.

The study recommends these models, particularly: TAGB = 0.067D<sup>2.474</sup> and TAGB = 0.000003855 (D<sup>2</sup>H)<sup>2</sup> + 0.023 (D<sup>2</sup>H) + 3.496, for biomass estimation of Benguet pine especially those with D that fall within 5 – 50 cm. Also, these models shall be used to account for the biomass and



carbon stored and sequestered by the secondary communal forest in Batayan, Tadian, Mountain Province including other carbon pools. These models can be improved and validated if applicable in Benguet pine forest in other areas. Further studies should be conducted to determine the actual carbon content of the different tree components. Moreover, allometric models for other common or dominant tree species should be developed to help in accurately accounting the carbon stored and sequestered in Philippine forest. This, in turn, will guide its monetization under the carbon trading scheme of the Kyoto Protocol. Lastly, reforestation and afforestation programs of the different agencies should be sustained and strengthened as these forests provide a lot of ecological services including carbon sequestration.

## ACKNOWLEDGMENT

The author is very grateful to his advisers Dr. Romeo A. Gomez, Dr. Erlinda C. Bestre and Dr. Denisa L. Domondon for their valuable advices and critiques for the improvement of the study. Also to Biology Laboratory being supervised by Ma'am Eslava and Soils Laboratory for the data analysis.

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